NASA Technical Memorandum

NASA TM- 100389

FEASIBILITY OF USING EXTREME ULTRAVIOLET EXPLORER REACTION WHEELS TO SATISFY SPACE INFRARED TELESCOPE FACILITY MANEUVER REQUIREMENTS

By W. D. Lightsey

Preliminary Design Office
Program Development Directorate

February 1990

(NASA-TM-100389) FEASIBILITY OF USING EXTREME ULTRAVIOLET EXPLORER (EUVE) REACTION WHEELS TO SATISFY SPACE INFRARED TELESCOPE FACILITY (SIRTF) MANEUVER REQUIREMENTS (NASA) 22 p — N90-19555
CSCL 14B G3/35 — Unclas 0271116

National Aeronautics and
Space Administration
George C. Marshall Space Flight Center

TABLE OF CONTENTS

PRECEDING PAGE BLANK NOT FILMED

LIST OF ILLUSTRATIONS

TECHNICAL MEMORANDUM

FEASIBILITY OF USING EXTREME ULTRAVIOLET EXPLORER (EUVE) REACTION WHEELS TO SATISFY SPACE INFRARED TELESCOPE FACILITY (SIRTF) MANEUVER REQUIREMENTS

INTRODUCTION

This effort investigates the feasibility of using the extreme ultraviolet explorer (EUVE) reaction wheels to provide the control torques for the space infrared telescope facility's (SIRTF) attitude control system (ACS). Use of the EUVE reaction wheels will result in a lighter ACS than if space telescope (ST) reaction wheels are used. This lighter ACS is desirable since the high altitude (100,000 km) SIRTF vehicle is weight critical.

In September 1989 the maneuver requirements for SIRTF were revised. Figure 1 shows a summary of the "new" maneuver requirements along with a summary of the previous requirements. Under the "old" requirements the 120-degree slew in 480 s is the most demanding of the slew maneuvers in terms of the actuator torque required to perform the maneuver. Under the "new" requirements the 7-arc-min maneuver in 30 s becomes the reaction wheel torque "driver." This 7-arc-min maneuver is the same for both the "old" and "new" requirements. Since the "new" roll requirement is less stringent than the "old," the "new" requirements as a whole are relaxed as compared to the "old" requirements.

OLD	NEW
SLEW 120° IN 480 SEC 30.0 ARC-SEC ACCURACY 0.15 ARC-SEC STABILITY	SLEW 180° IN 1000 SEC 0.25 ARC-SEC ACCURACY 0.15 ARC-SEC STABILITY
SLEW 7 ARC-MIN IN 30 SEC 0.25 ARC-SEC ACCURACY 0.15 ARC-SEC STABILITY	SLEW 7 ARC-MIN IN 30 SEC 0.25 ARC-SEC ACCURACY 0.15 ARC-SEC STABILITY
ROLL 67.5° IN 270 SEC 30.0 ARC-SEC ACCURACY 0.15 ARC-SEC STABILITY	ROLL 45° IN 600 SEC 0.25 ARC-SEC ACCURACY 0.15 ARC-SEC STABILITY

Figure 1. SIRTF maneuver requirements.

PCS SIMULATION

A digital simulation was developed to analyze SIRTF's pointing control system (PCS). Figure 2 shows a simpified block diagram of the PCS implemented in the simulation. Maneuvers are controlled by the maneuver acceleration command $\dot{\omega}_c$ shown in the block diagram. The gains K_I, K_P, and K_R are normalized with respect to the vehicle inertia so that inertia changes will not require the gains to be changed.

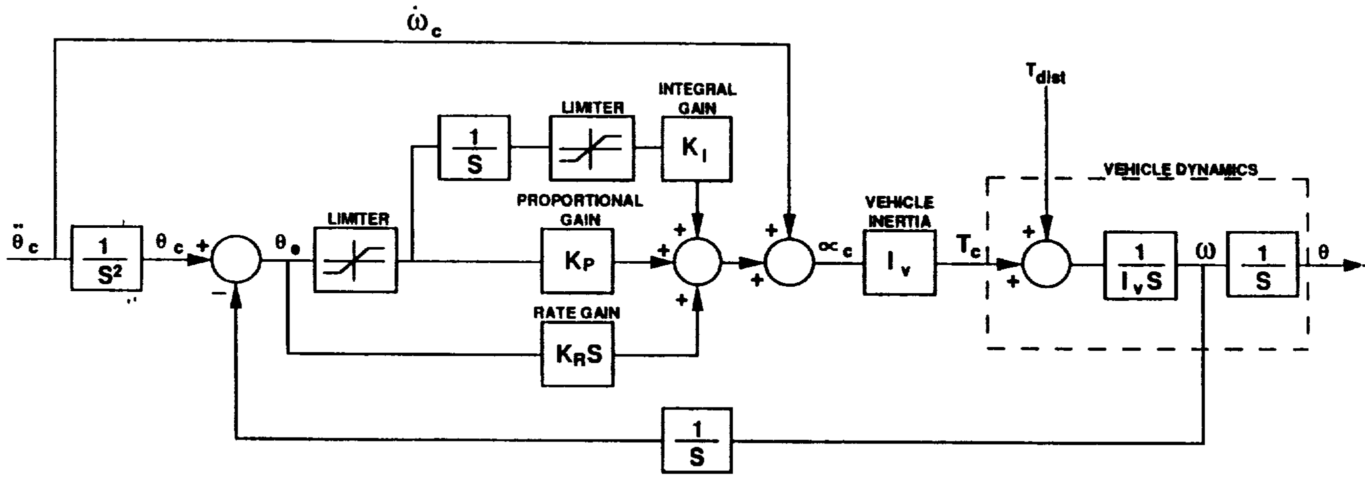
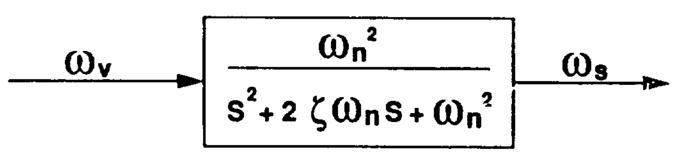


Figure 2. PCS block diagram (ideal system).

Simple models were used for the actuators and sensors. Figure 3 shows the second-order dynamic model used for the gyros. The simulation also includes a quantization level and a sampling period for the gyros. A second-order model was also used to represent a single vehicle bending mode about each axis. The vehicle rate resulting from the bending mode is added to the rigid-body vehicle rate at the gyro node.

Figure 4 shows the model used to represent the solar array bending. As with the bending mode models, the resultant vehicle rate caused by the solar array bending is added to the vehicle rate at the gyro node. Since solar pressure will be the dominant environmental disturbance at the high SIRTF orbit (100,000 km), a solar pressure disturbance is included in the simulation. Since the viewing constraints of SIRTF will keep the solar array within 30 degrees of perpendicular to the Sun line, a constant value was assumed for the solar pressure torque. The parameters used in the solar pressure calculation are shown in Figure 5.



$$\ddot{\omega}_s + 2\zeta\,\omega_n\,\dot{\omega}_s + \omega_n^2\,\omega_s = \omega_n^2\,\omega_v$$

$$\begin{Bmatrix}\ddot{\omega}_s\\ \dot{\omega}_s\end{Bmatrix} = \begin{bmatrix}-2\zeta\omega_n & -\omega_n^2\\ 1 & 0\end{bmatrix}\begin{Bmatrix}\dot{\omega}_s\\ \omega_s\end{Bmatrix} + \begin{bmatrix}\omega_n^2\\ 0\end{bmatrix}\{\omega_v\}$$

$$\omega_n = 27.96\ H_z\ ;\quad \zeta = 1.0$$

Figure 3. Gyro dynamic model.

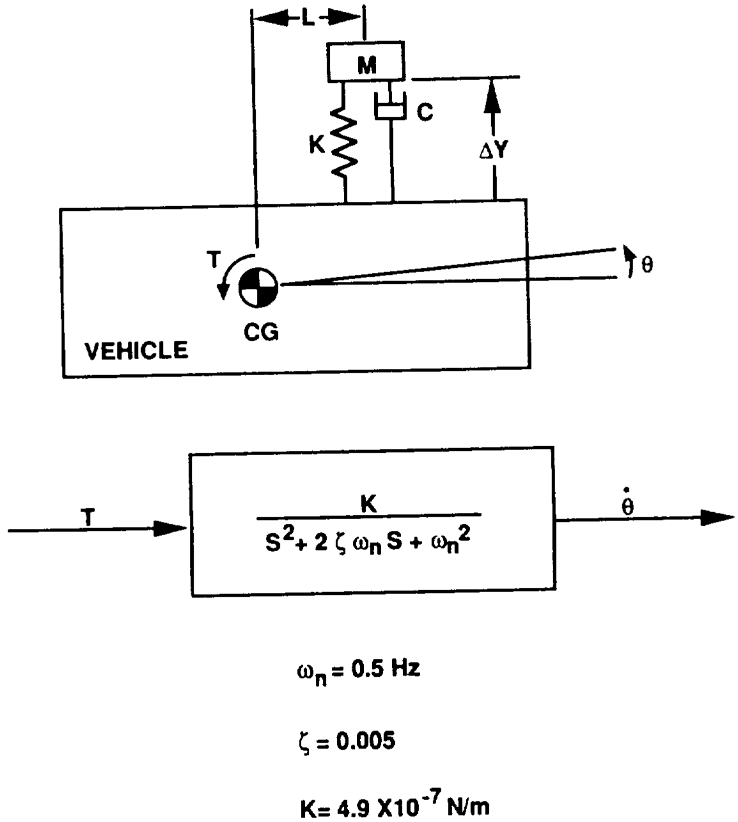


Figure 4. Solar array dynamic model.

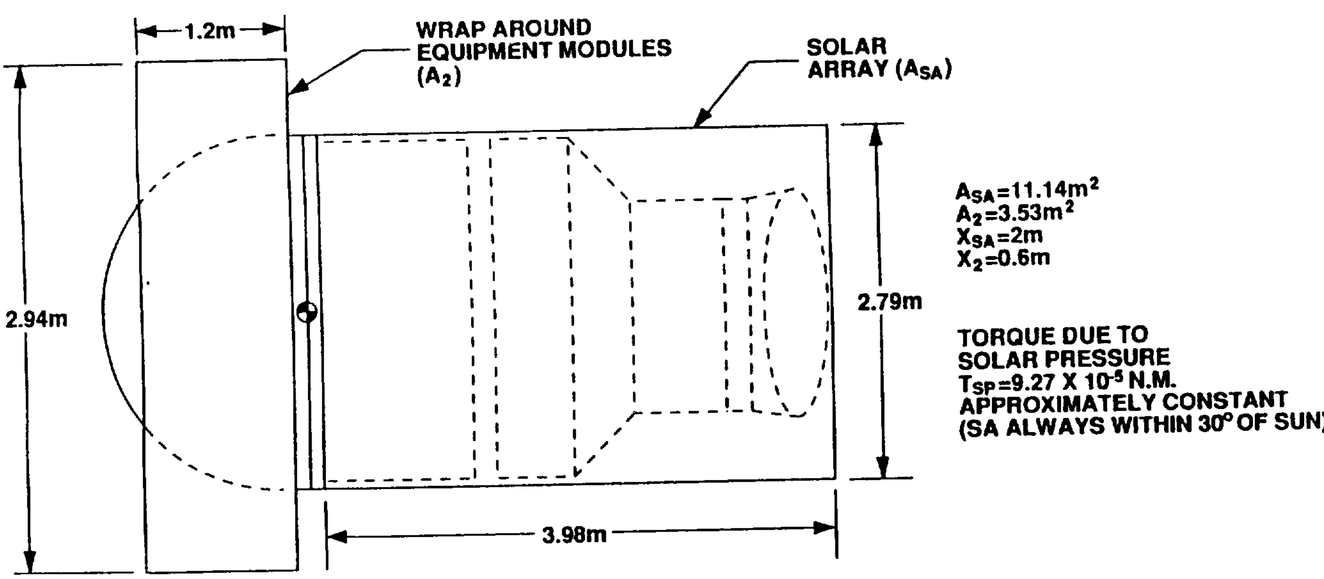


Figure 5. Solar pressure disturbance torque calculation parameters.

The reaction wheels are assumed to be ideal except for a torque quantization level and a maximum-output torque limit. The simulation also contains a distribution law which attempts to distribute the residual wheel momentum equally among the four reaction wheels.

Many of the parameter values used in the models previously discussed (i.e., damping, natural frequencies, etc.) come from ST data. Where ST data did not seem reasonable or was not available, values were assumed based on intuition. This was necessary because, at this early stage, actual values for many of the parameters simply are not available.

The vehicle concept used in the simulation is shown in Figure 6. This is the "wraparound" concept where the spacecraft structure is mounted about the periphery of the aft end of the telescope, and the solar array is side-mounted to the telescope. The vehicle inertias are given in the figure.

The reaction wheel configuration used in the simulation is shown in Figure 7. This configuration is adapted from ST. Mathematically, the arrangement is equivalent to a pyramidal configuration, but the physical arrangement is due to packaging considerations on ST. Under the "old" maneuver requirements it was necessary to increase the 20-degree inclination angle (Fig. 7), placing more torque along the roll axis, in order to meet the roll maneuver requirement. Because of this, the torque available for the slew maneuvers was reduced. Under the "new" requirements, the roll maneuver is less stringent, allowing the inclination angle to be returned to its 20-degree value.

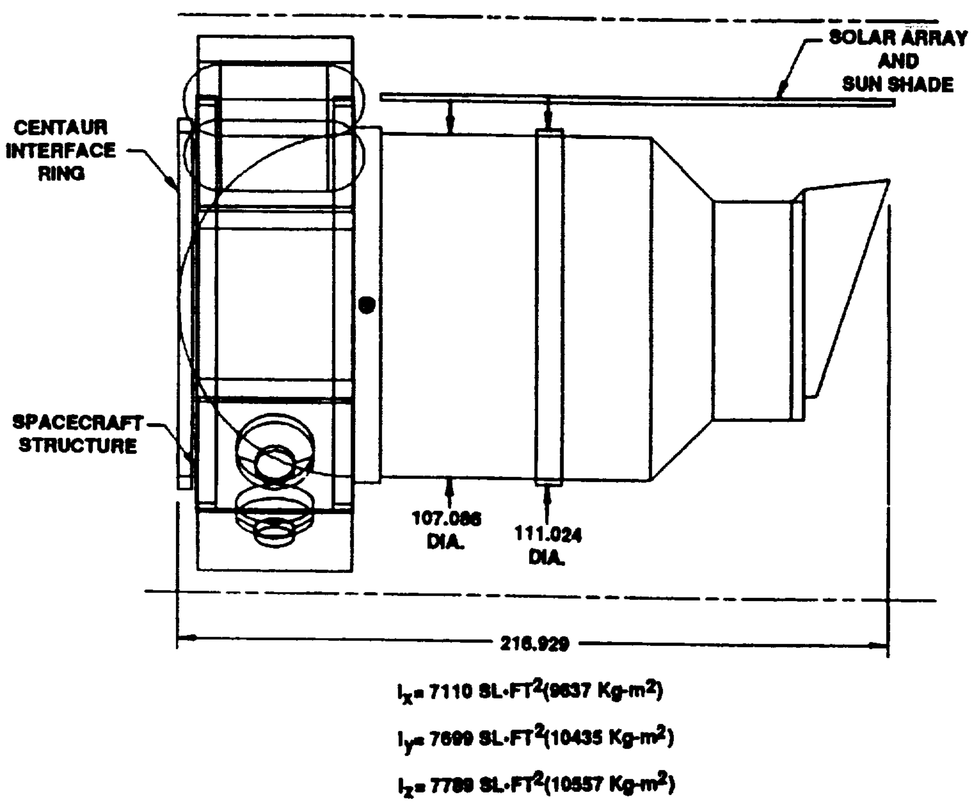


Figure 6. Wraparound spacecraft.

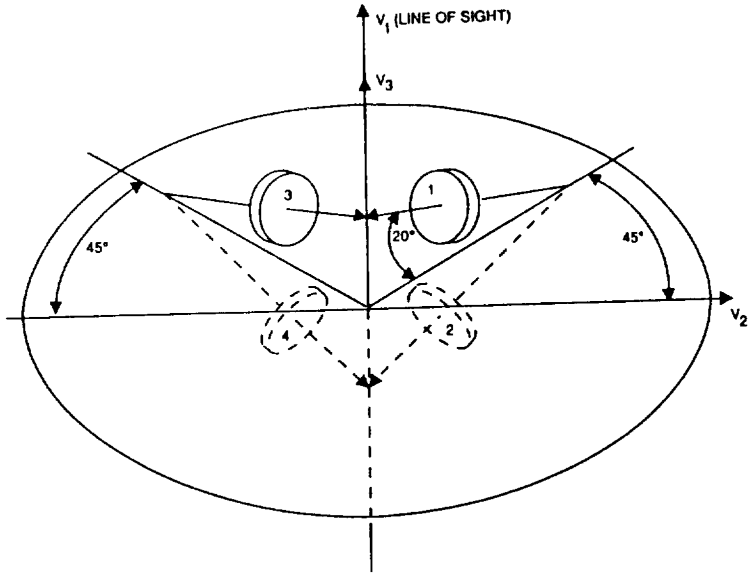
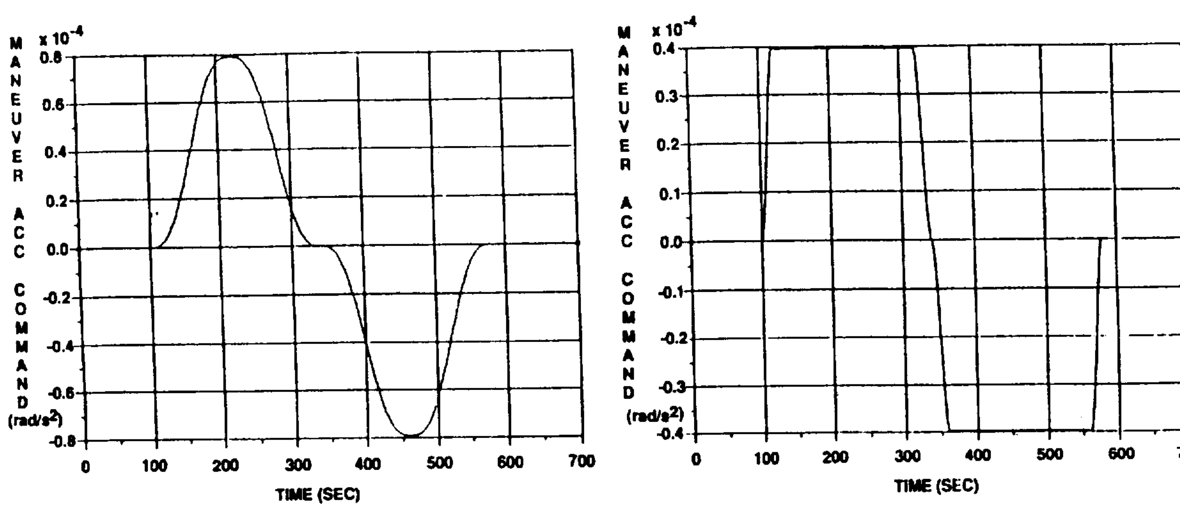


Figure 7. Reaction wheel configuration.

The maneuver acceleration command profile $\dot{\omega}_c$ (Fig. 2) is shown in Figure 8. This profile determines the reaction wheel torque profile. Figure 8(a) shows a smooth profile with no dwell time at peak acceleration. This is a jerk-minimizing profile that is desirable because it will minimize the excitation of bending modes. The modified profile of Figure 8(b) was necessary under the "old" maneuver requirements. The reaction wheels were ramped up to their peak torque value and held at that value for a period of time. This was necessary because of insufficient control torque. This profile results in increased jerk on the vehicle and may not even be feasible if the ramp-up time becomes smaller than that which the actual reaction wheels can provide. This modified profile is not required to meet the "new" maneuver requirements. A similar profile could be used, however, if an increased settling period at the end of a maneuver becomes necessary. This would be a trade since the modified profile increases vehicle disturbance and may require a longer settling time.



(a) ST reaction wheels. **(b) EUVE reaction wheels.**

Figure 8. Maneuver acceleration command profiles.

HELIUM SLOSH

A major concern regarding attitude control is the effect that the superfluid helium motion will have on the vehicle attitude. Little data can be found concerning the behavior of superfluid helium in a zero-g environment. The superfluid helium exhibits properties uncommon to those of a "normal" fluid such as water. Because of this, propellant slosh models derived for "normal" fluids may be useless for modeling superfluid helium "slosh."

In order to get some idea of the settling times that may be required at the end of maneuvers due to the helium slosh, a highly simplified slosh disturbance model is assumed. This model strives to represent a "worst case" disturbance that might occur due to sloshing, but in no way attempts to represent the actual dynamics of the superfluid helium. If acceptable performance can be obtained under the "worst case" model, then it is not likely that the disturbance due to the actual helium slosh will adversely affect the vehicle's pointing ability.

The disturbance torque due to sloshing that occurs at the end of a maneuver is assumed to be in the form of a sinusoid that decays over time, and is expressed as

$$T_d = T_{do} \, e^{-\zeta \omega_n t} \sin (\omega_d t) \ .$$

A typical disturbance signal T_d is shown in Figure 9. Since little is known about the behavior of the helium, values must be assumed for ω_n and ζ. The values used in this effort are $\omega_n = 0.25$ Hz and $\zeta = 0.1$. To obtain a value for T_{do} the entire fluid mass of 580 kg is assumed to be a point mass (Fig. 10). This mass is assumed to be moving relative to the tank wall at a velocity equal to the maximum tangential velocity that it would obtain during the maneuver. Any friction or interaction between the fluid and tank is neglected. At the instant the maneuver terminates, the fluid collides with the tank wall, transferring its momentum to the vehicle. Using an impact duration of 3 s along with the vehicle geometry, a value for T_{do} of approximately 0.05 N·m results.

Although the above model is intended to represent a "worst case" slosh disturbance, several assumptions were made and some guess work was required to derive the model. In light of this, it is questionable whether or not the model is truly a "worst case" model. It is probably best to state that, rather than neglecting slosh entirely, some disturbance model is included here, and the performance of the system in the presence of this disturbance can be assessed. A parametric study could result in some "maximum allowable disturbance" being determined.

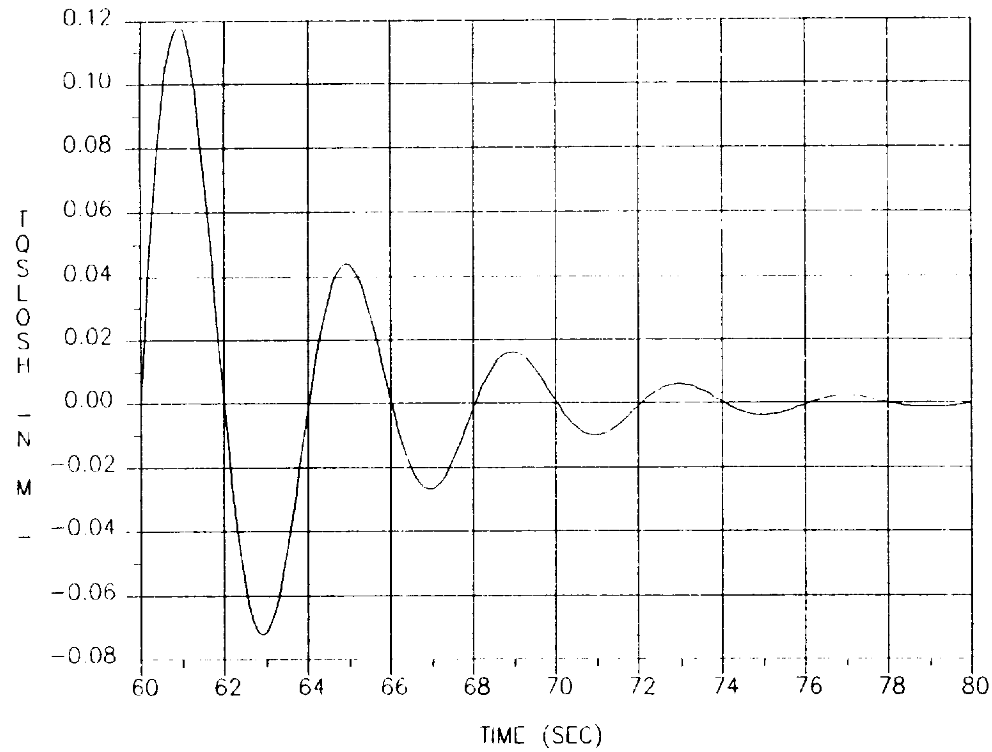


Figure 9. Slosh disturbance signal.

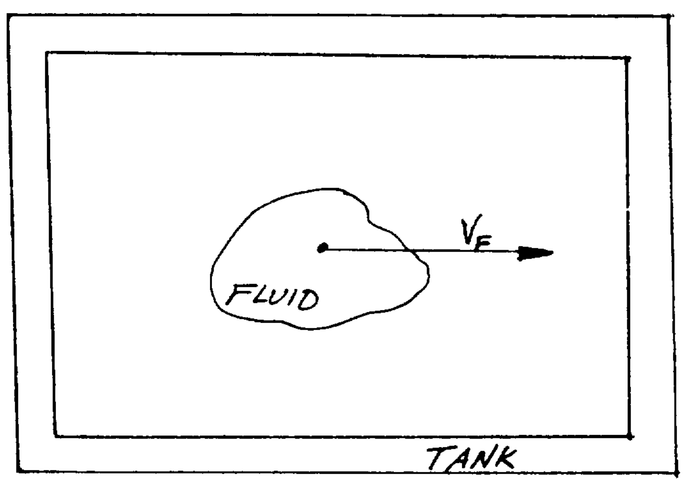


Figure 10. Fluid/tank interaction.

SIMULATION RESULTS

A 7-arc-min right ascension slew is shown in Figure 11. To simulate a "limiting case" slew maneuver, the roll attitude is fixed at 45-degrees and the declination change is zero. In this configuration two of the reaction wheels are perpendicular to the maneuver axis and, therefore, cannot contribute any torque along this axis. This leaves two reaction wheels to bear the load of maneuvering the vehicle. There exists an infinite number of these "limiting" cases. The right ascension maneuver was used to make the results easier to visualize.

ORIGINAL PAGE IS
OF POOR QUALITY

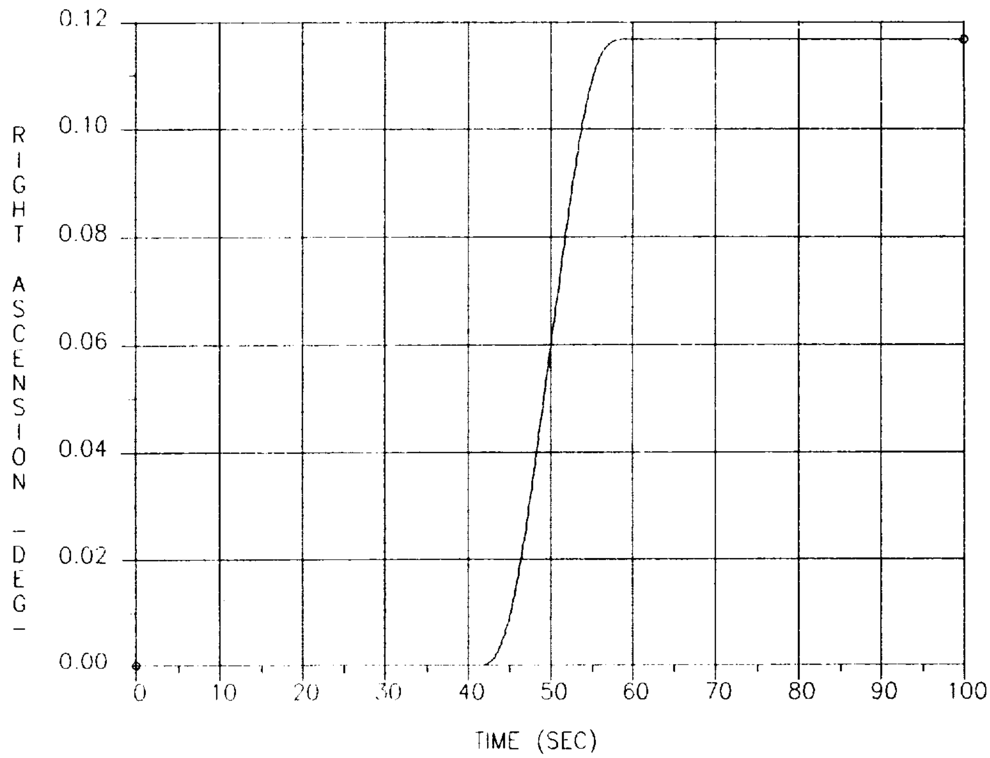


Figure 11. Right ascension change for 7-arc-min maneuver.

The maneuver begins at 40 s into the run and terminates at t = 60 s, allowing a 10-s settling period. Figure 12 shows the right ascension attitude error being driven to zero at t = 60 s. In Figure 13 this plot has been magnified at the maneuver ending period. It can be seen that at the end of the settling period (t = 70 s) the error is well within the 0.15 arc-s stability and 0.25 arc-s accuracy requirements.

Figure 14 shows a similar magnified view for the declination error. The effect of the slosh disturbance is seen here. At t = 70 s, the pointing requirements are being satisfied, but the stability is only marginally within its bounds. The roll error is shown in Figure 15. Again the slosh disturbance shows up in the roll response. The stability requirement is again marginally satisfied.

Notice that the disturbance torque effects do not show up in the right ascension error response (Fig. 13). This is because the same disturbance signal is being applied about each of the vehicle axes. Since the roll attitude is 45 degrees, the disturbance components along the right ascension axis cancel while the components along the declination axis complement each other.

The reaction wheel torque signals are shown in Figure 16. Notice that wheels one and two are not being used during the maneuver since they are perpendicular to the axis about which the vehicle is being rotated. Wheels three and four reach peak torque values of about 0.23 N·m. The maximum torque available from the EUVE reaction wheels is 0.296 N·m. Therefore, a small margin exists which could be used to provide a slightly longer settle-out period by ending the maneuver sooner. Ideally, this is feasible, but in the real world some torque margin will be necessary. (Available torque is a function of wheel speed.)

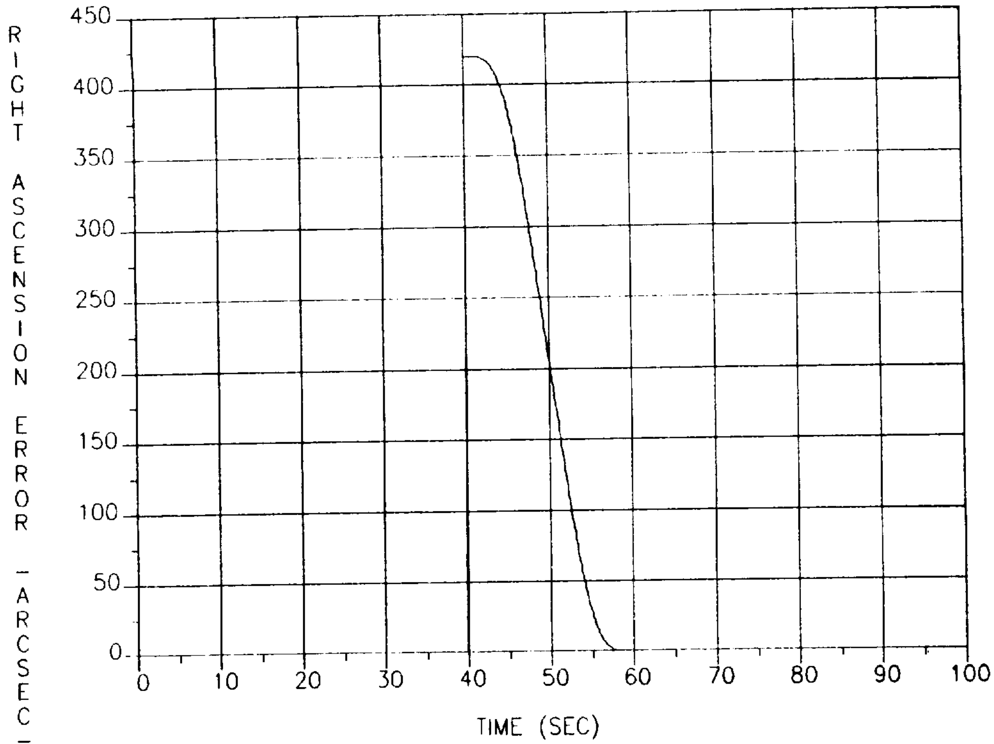


Figure 12. Right ascension attitude error.

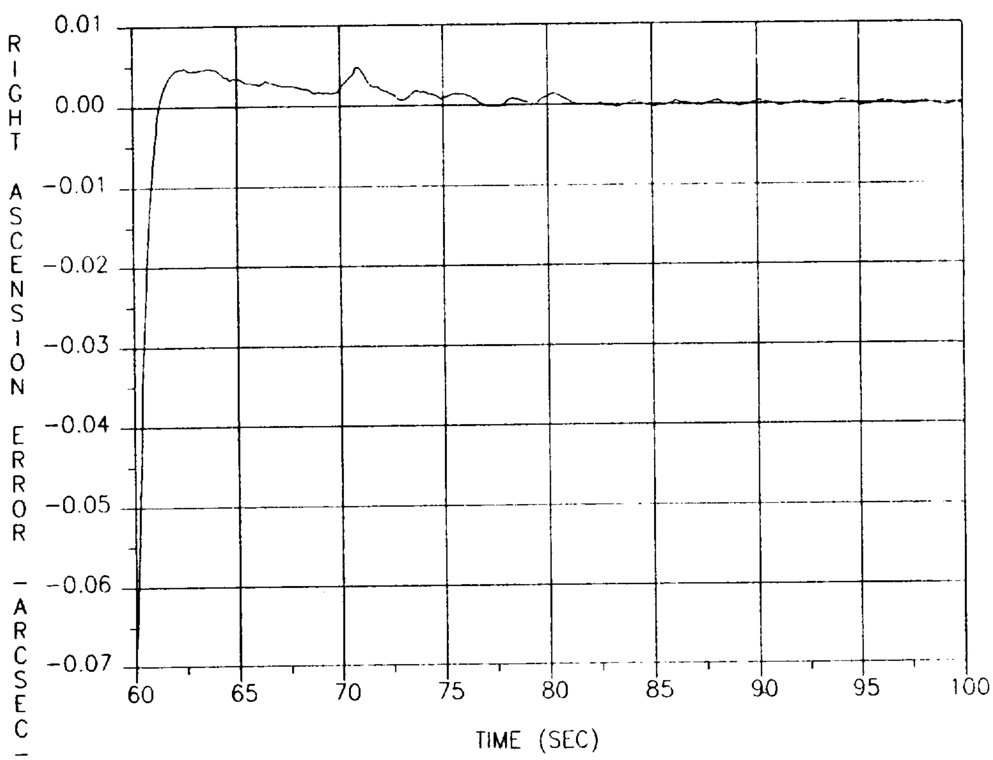


Figure 13. Right ascension attitude error (magnified view).

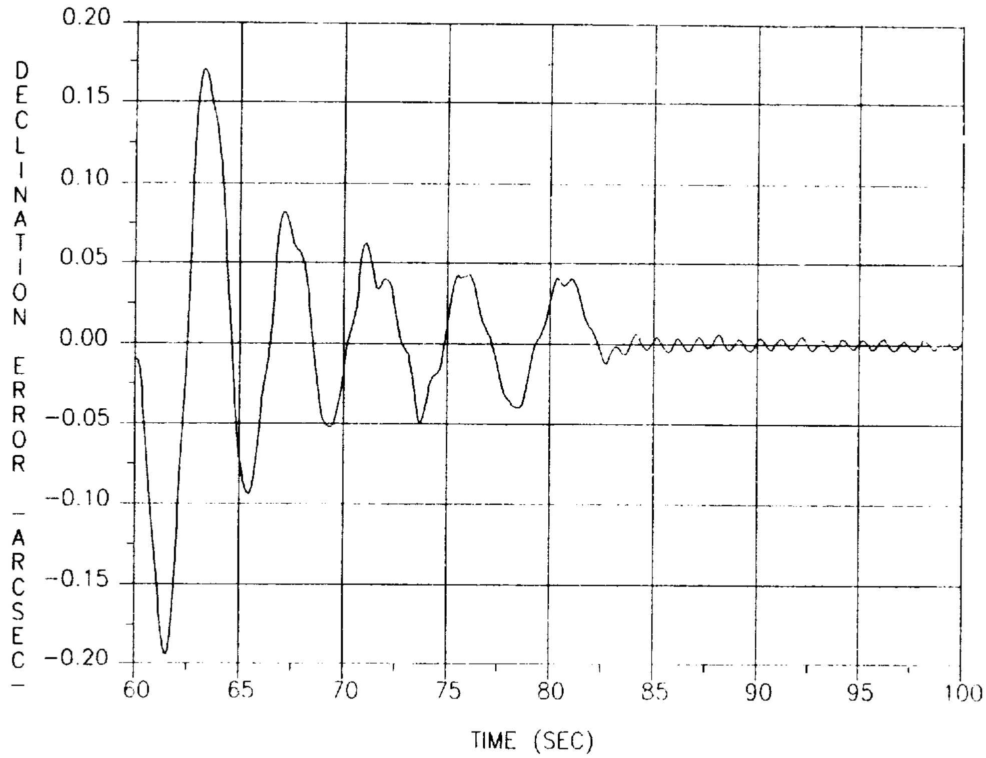


Figure 14. Declination error signal.

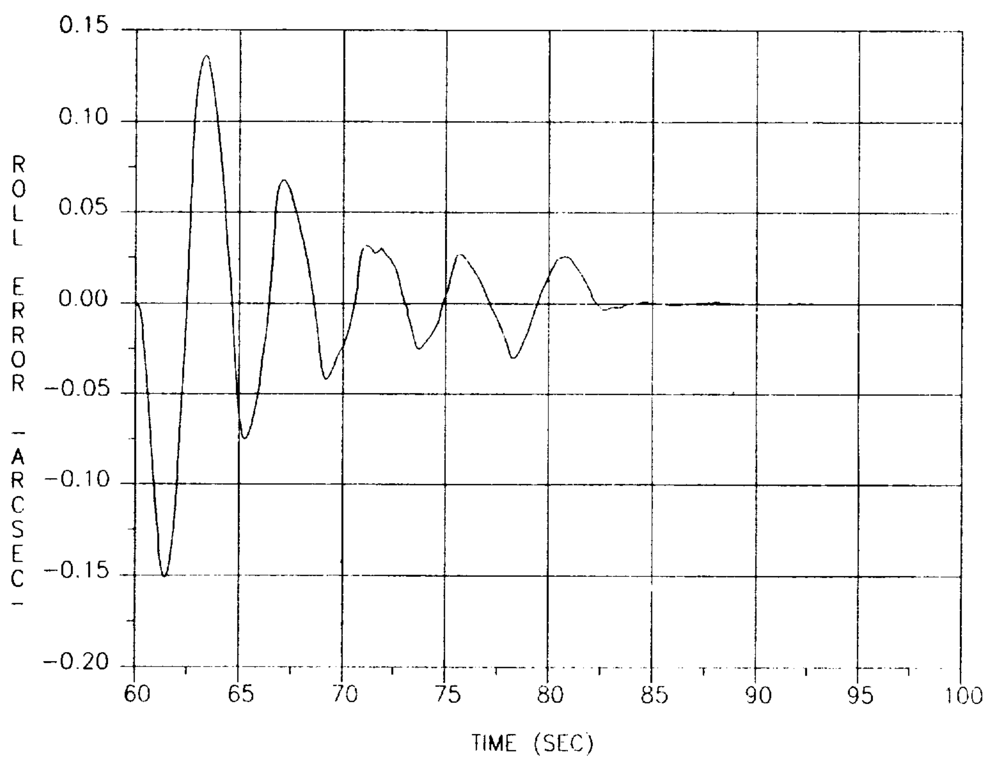


Figure 15. Roll error signal.

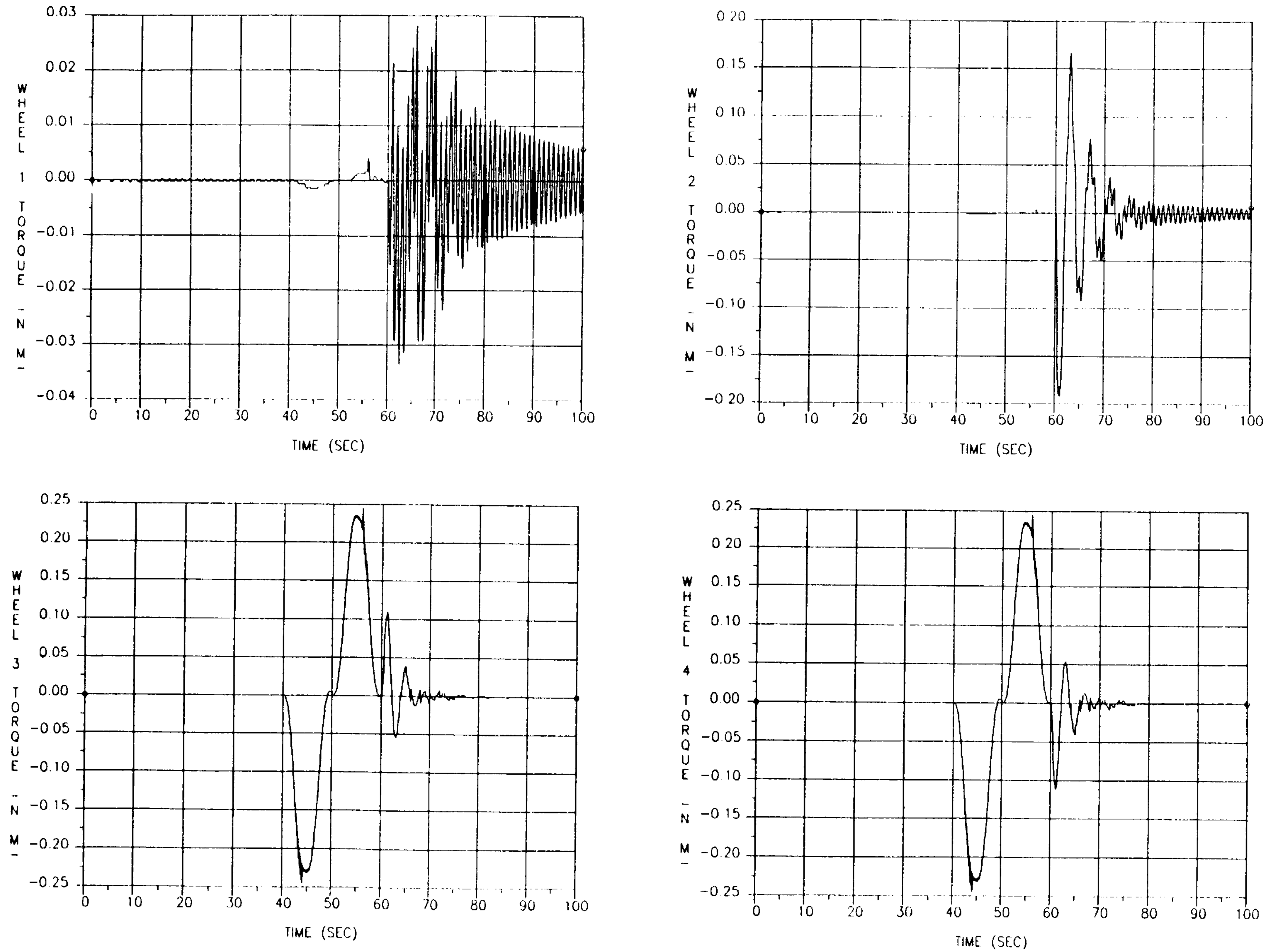


Figure 16. Reaction wheel torque profiles.

Figures 17 through 22 show the results of the 45-degree roll maneuver. In this case the maneuver begins at t = 50 s and terminates at t = 620 s, allowing a 30-s settling period. Since the roll attitude is 45 degrees at the end of the maneuver, the slosh disturbance is once again cancelled about the right ascension axis. By the end of the settling period (t = 650 s), all three error signals have settled well below their required values.

A look at the wheel torques in Figure 22 shows that the peak torque of each wheel during the maneuver is about 0.13 N·m, well below the 0.296 N·m limit. Because of this, the inclination angle in the reaction wheel configuration could be reduced from 20 degrees, thus providing more torque for slew maneuvers. This would allow an increase of the settle-out period for the 7-arc-min slew maneuver, thus allowing the stability requirement to be better satisfied.

In addition to having sufficient control torque to perform maneuvers, the momentum capability of the EUVE reaction wheels must also be sufficient. Figure 23 shows the momentum of reaction wheel three for the 7-arc-min slew maneuver. The wheel four momentum profile is similar (since the wheels were torqued the same) and the momentum of wheels one and two is essentially zero, since these two wheels were only slightly torqued during the maneuver. The momentum storage capability of the EUVE reaction wheels is 81.4 N·m·s which is well above the peak momentum value of 1.15 N·m·s reached by reaction wheels three and four.

In Figure 24 the momentum of wheel one for the 45-degree roll maneuver is shown. Since all the wheels were torqued equally (in magnitude) during the maneuver, the remaining three wheels will have similar momentum profiles. Again, only 19 N·m·s is required for the manuevers, which is about 23.5 percent of the EUVE wheel capability.

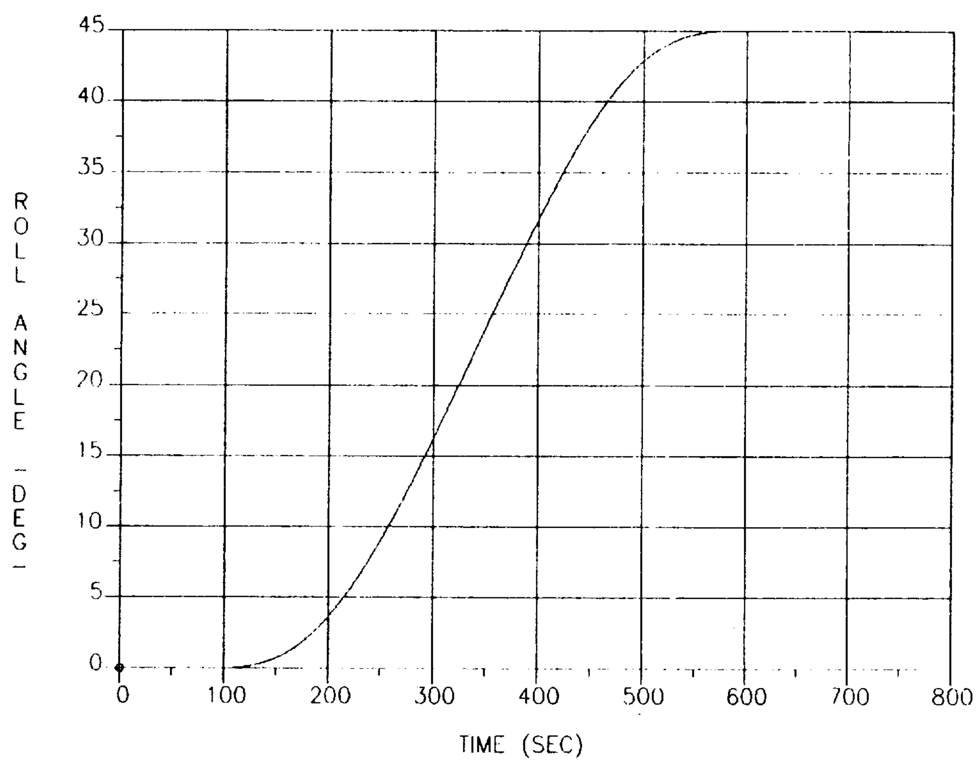


Figure 17. Change in roll attitude for 45-degree roll maneuver.

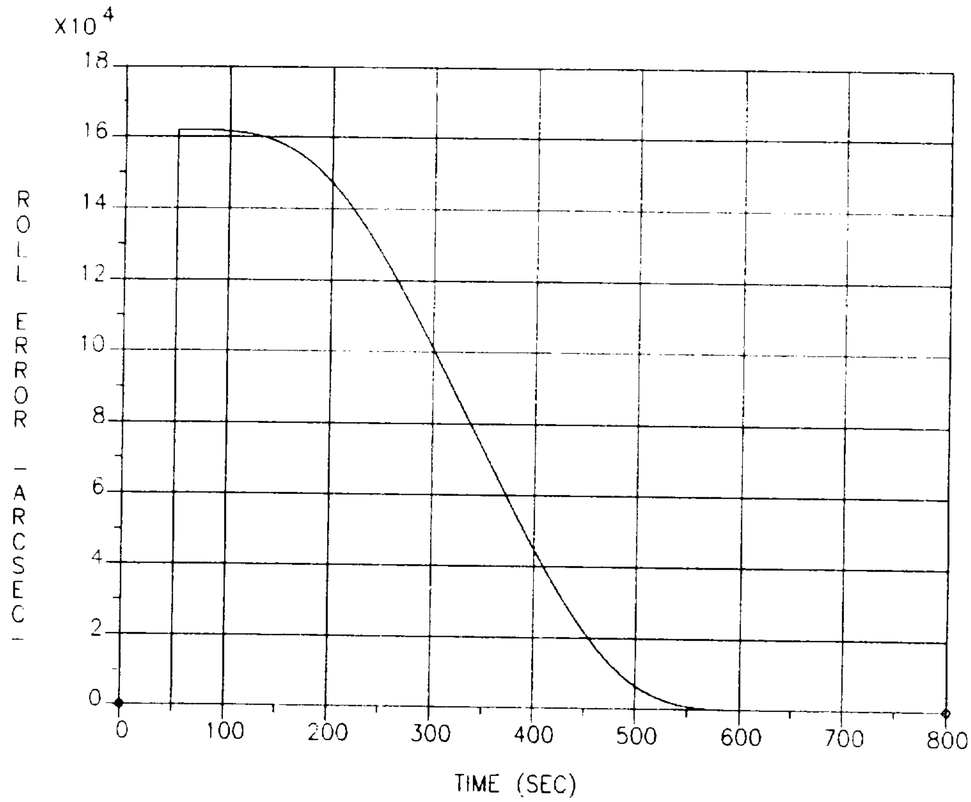


Figure 18. Roll attitude error.

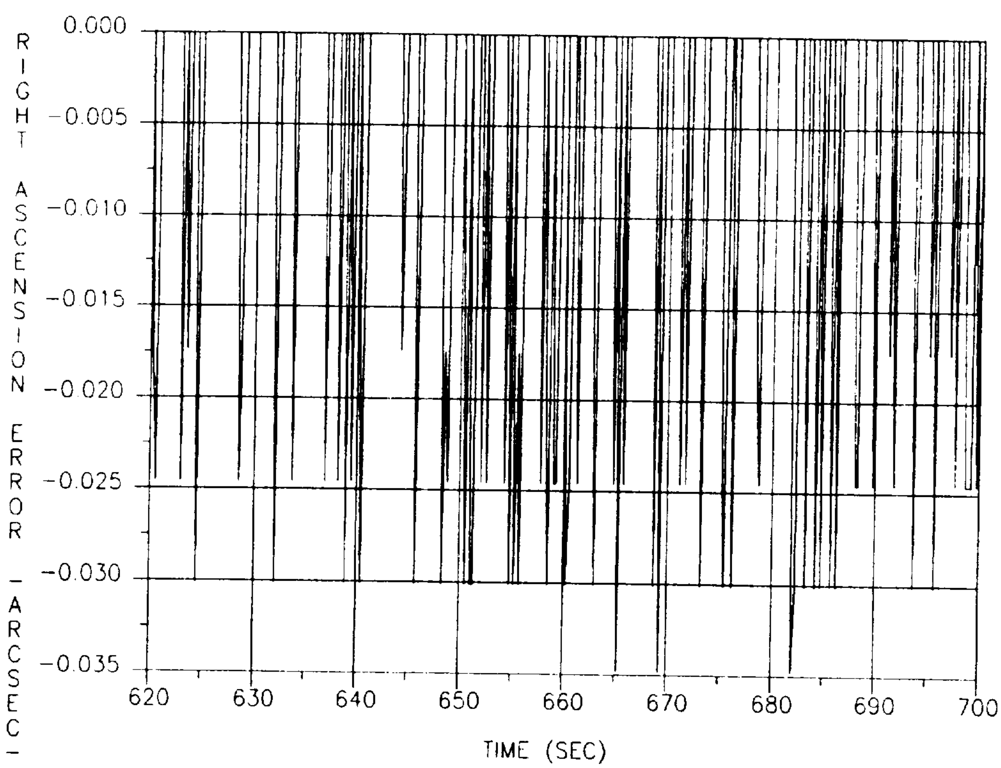


Figure 19. Right ascension error (magnified view).

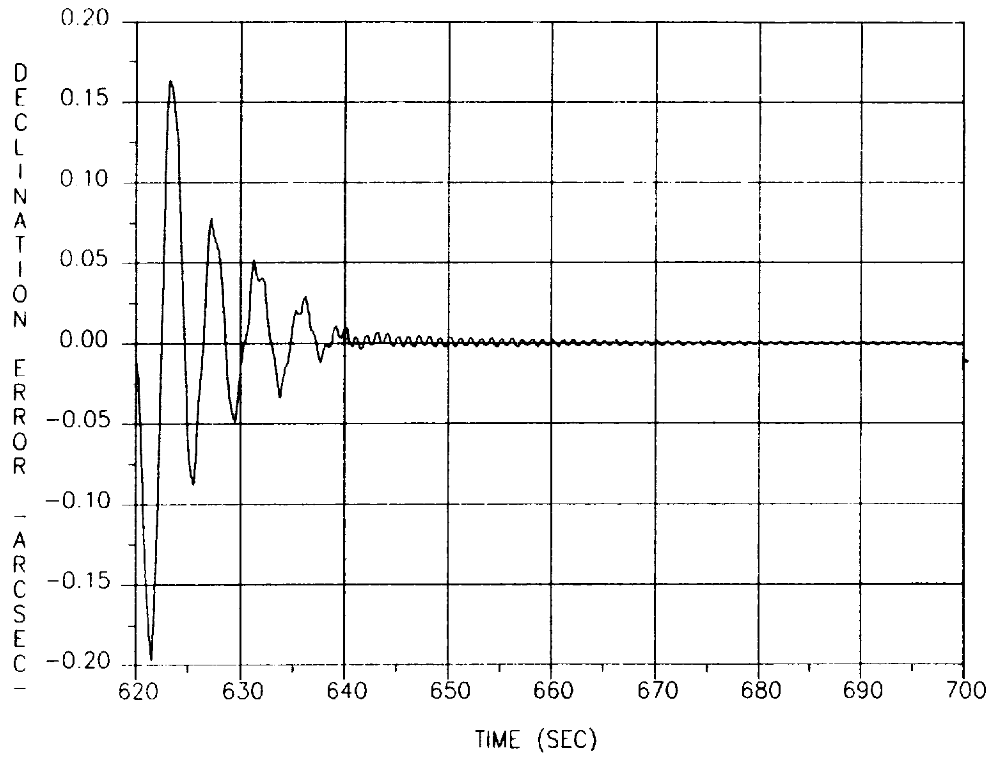


Figure 20. Declination error signal.

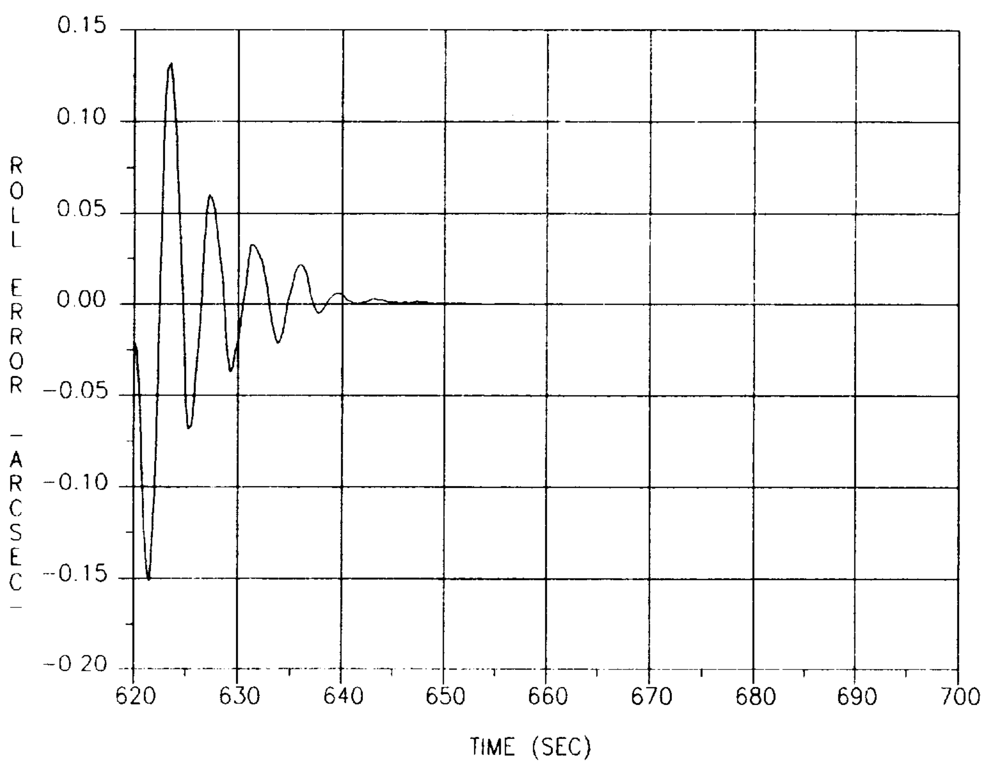


Figure 21. Roll error signal.

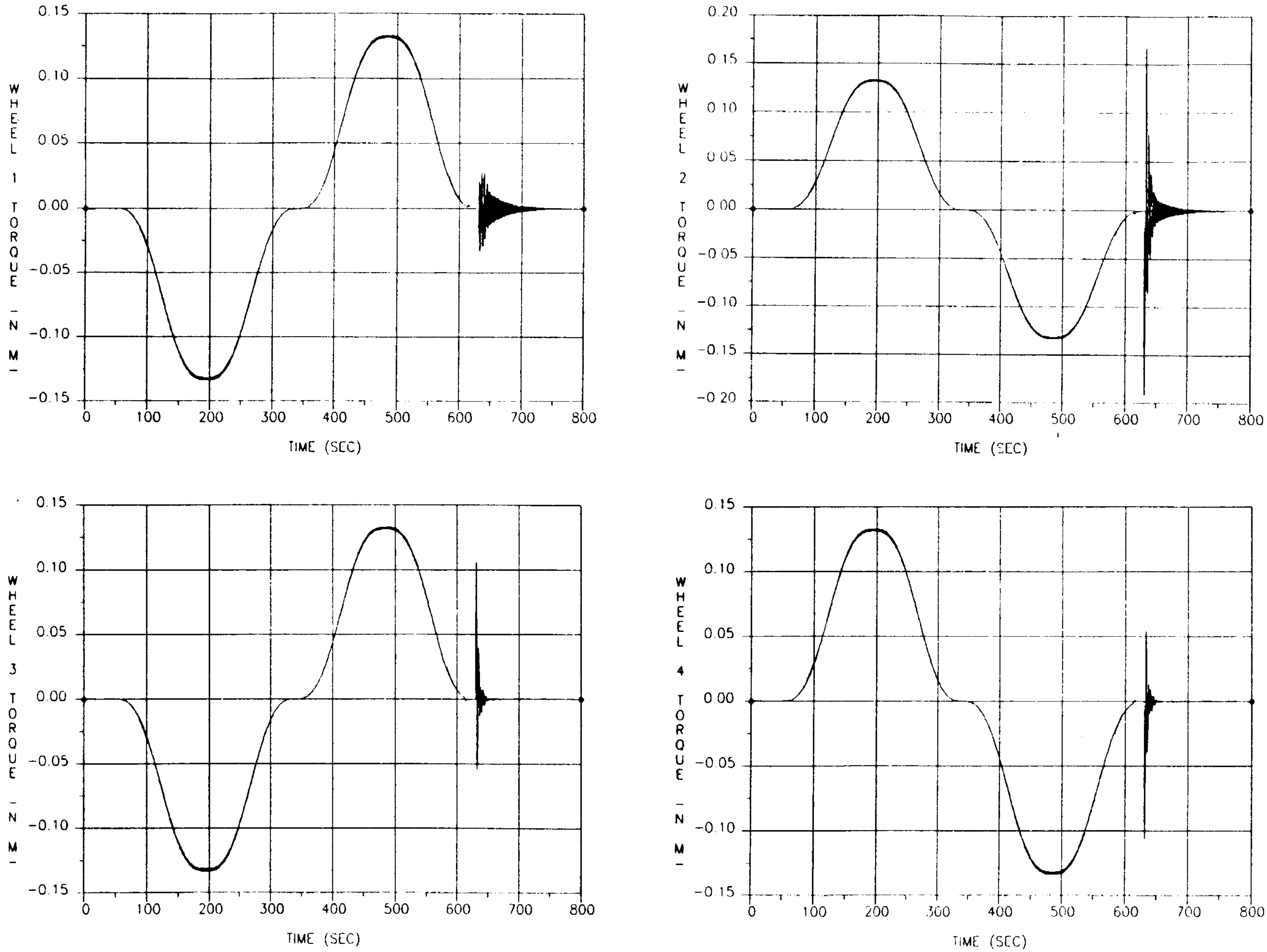


Figure 22. Reaction wheel torque profiles.

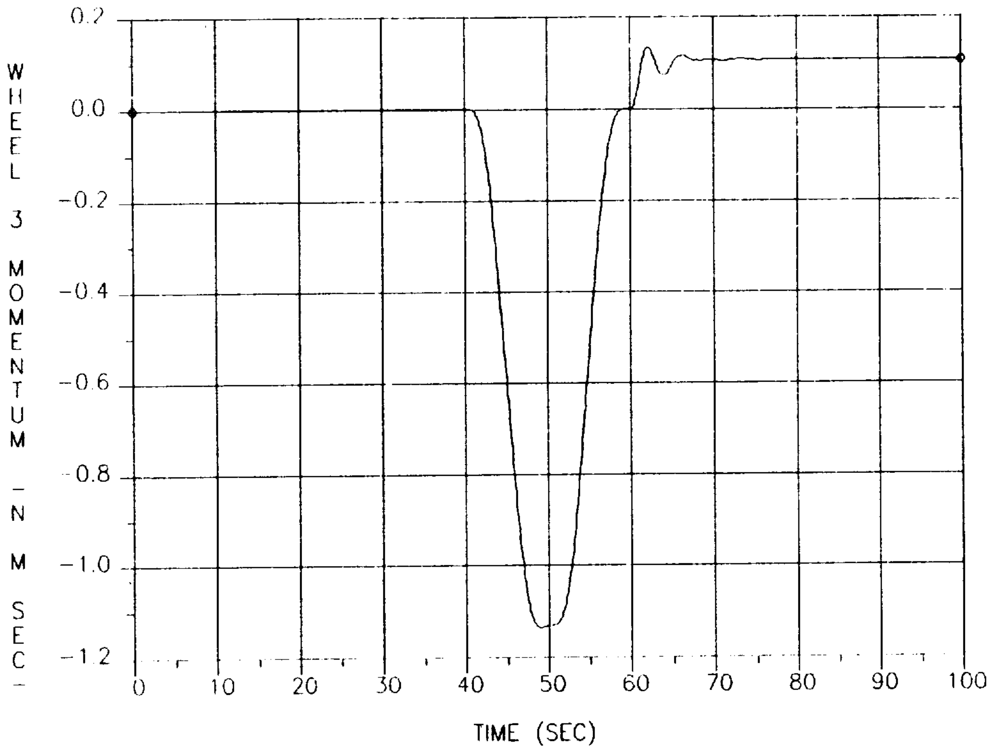


Figure 23. Wheel No. 3 momentum profile, 7-arc-min maneuver.

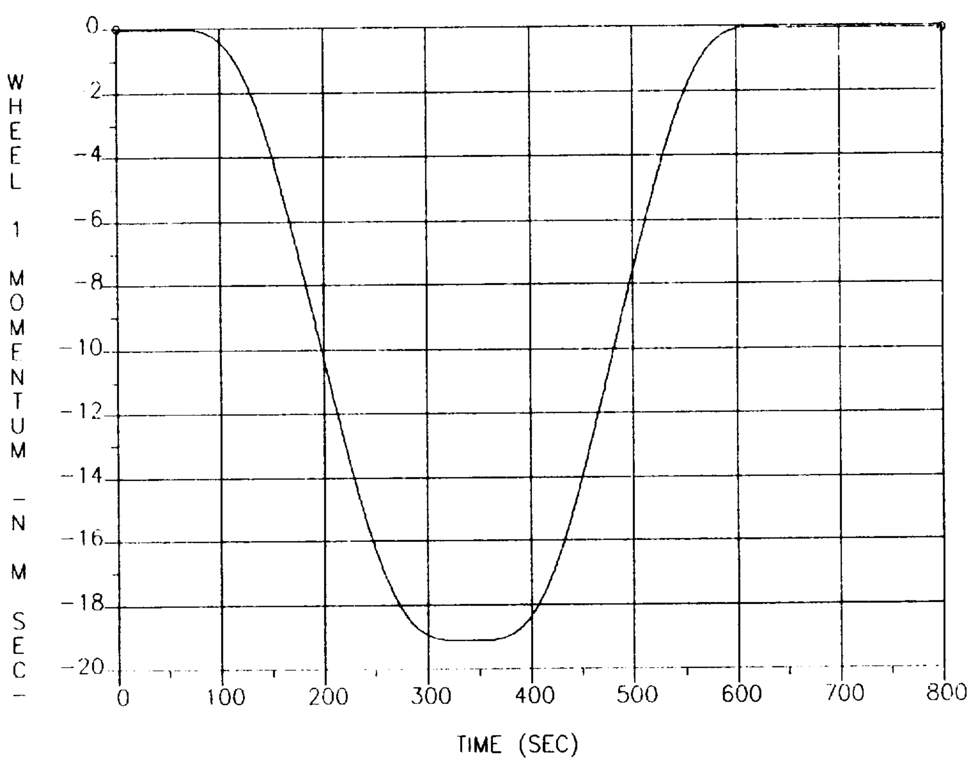


Figure 24. Wheel No. 1 momentum profile, 45-degree roll maneuver.

A simulation of the third required maneuver, 180-degree slew in 1,000 s, was made to see if sufficient momentum storage is available for this maneuver also. This maneuver required 37 N·m·s of momentum storage which is 45.5 percent of the EUVE wheel capabilty.

CONCLUSION

The results generated with the present system model indicate that, with respect to wheel torque and momentum storage capability, the EUVE reaction wheel is an attractive candidate for SIRTF. A more detailed model of the reaction wheel will be necessary to assess the wheels behavior in fine-pointing situations (torque ripple, etc.).

For each of the three required maneuvers ample torque and momentum is available to complete the maneuver and allow a settle-out period for transients that may occur at the end of the maneuver. In the present analysis, the settle-out periods were sufficient to allow the transients due to the disturbance model to decay to acceptable levels.

These results were generated using a set of four reaction wheels as previously discussed. Although no "wheel out" studies were performed under the "new" maneuver requirements, it appears obvious, especially for the 7-arc-min slew, that the required maneuver could not be performed in the event of a wheel failure. For this reason, a configuration consisting of more than four wheels (probably six) will probably be required. This will increase the ACS weight but the system will still be lighter than if four ST reaction wheels are used.

APPROVAL

FEASIBILITY OF USING EXTREME ULTRAVIOLET EXPLORER REACTION WHEELS TO SATISFY SPACE INFRARED TELESCOPE FACILITY MANEUVER REQUIREMENTS

By W.D. Lightsey

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

Charles R. Darwin

CHARLES R. DARWIN
Director, Program Development

☆ U.S. GOVERNMENT PRINTING OFFICE 1990—731-061/20049

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-100389		

4. Title and Subtitle	5. Report Date
Feasibility of Using Extreme Ultraviolet Explorer (EUVE) Reaction Wheels to Satisfy Space Infrared Telescope Facility (SIRTF) Maneuver Requirements	February 1990
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
W. D. Lightsey	
	10. Work Unit No.
9. Performing Organization Name and Address	11. Contract or Grant No.
George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812	
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared by Preliminary Design Office, Program Development Directorate.

16. Abstract

A digital computer simulation is used to determine if the extreme ultraviolet explorer (EUVE) reaction wheels can provide sufficient torque and momentum storage capability to meet the space infrared telescope facility (SIRTF) maneuver requirements. A brief description of the pointing control system (PCS) and the sensor and actuator dynamic models used in the simulation is presented. A model to represent a disturbance such as fluid sloshing is developed. Results developed with the simulation, and a discussion of these results are presented.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Pointing requirements, reaction wheels, dynamics, momentum storage, vehicle rates	Unclassified – Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	21	NTIS

NASA FORM 1626 OCT 86

For sale by the National Technical Information Service, Springfield, VA 22161-2171